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Lubrication

A Technical Publication Devoted to the Selection and Use of Lubricants

THIS ISSUE

Lubrication Requirements of Metal Forming Machinery

Thin Oil Film Lubrication

Lubrication Service

PUBLISHED BY
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Lubrication Requirements of Metal Forming Machinery

PRESSURE as adapted to the formation of metals has become widespread in the production of automotive equipment, household appliances and a multitude of industrial operations. The demand for mass production has played an important part in this development. It has definitely proved the advantage of the power press for blanking, drawing, forming, forging and stamping of sheet metal. On such equipment continuous or intermittent high pressures on many of the moving parts may involve a degree of potential wear which must never be overlooked. The most careful selection of lubricants must therefore be exercised. Normally, the prevailing operating conditions will also include fairly high speeds, the presence of excessive amounts of dust, dirt and metallic particles, which might contaminate the lubricants, and oftentimes considerable temperature. All impose a load upon any lubricant, which requires thoughtful study of physical characteristics in the interest of obtaining products of adequate temperature-resisting and load-carrying capacity. Both lubricating oils and greases of suitable viscosity or consistency are applicable according to the type of lubricating system provided. These latter must, therefore, be thoroughly understood; their principles of operation will be of particular interest in connection with study of the lubrication requirements and lubricant characteristics for press operation.

Inasmuch as pressure is the ultimate factor in the operation of the metal press, etc., it is well to consider the working elements of the machinery involved and study any effect which such pressure may have upon the lubricating films. On much of this kind of machinery there will be constant normal pressures on the back shafts, with high intermittent pressures on the main bearings. These latter under working conditions will, in the majority of cases, run about four to five thousand pounds per square inch.

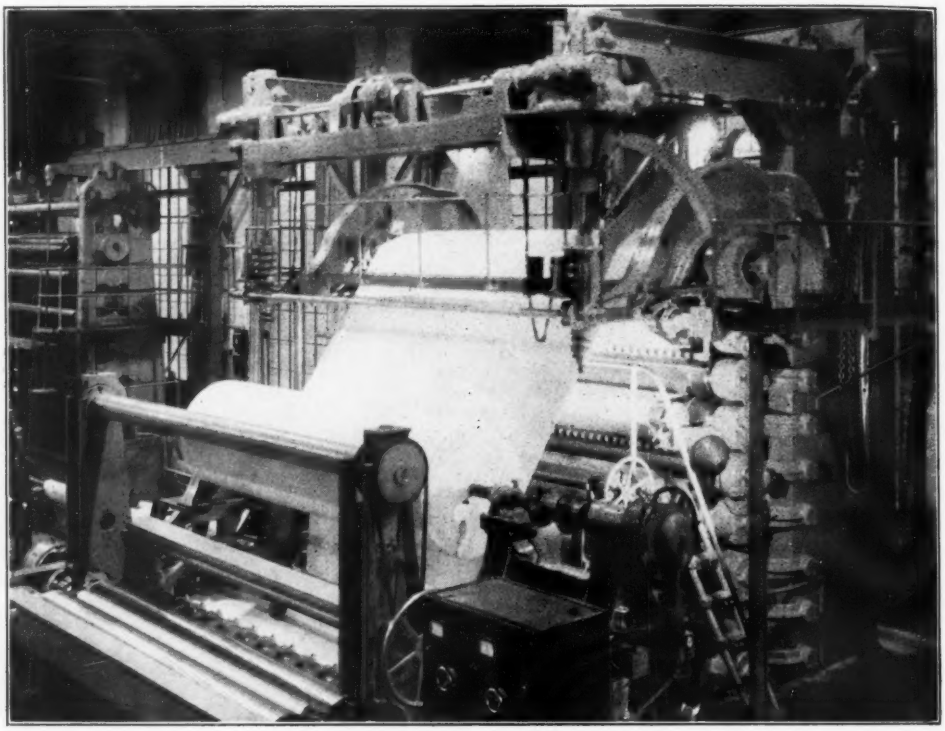
This is normally regarded as reactionary pressure or, in other words, the pressure which reacts back through the working parts as the press, slide, ram, or other particular metal-forming element performs its function. When such a machine is idling, the reaction or back pressure will frequently be comparatively low, even though a potential working pressure of thousands of pounds per square inch may be available when the machine is put into production.

Pressure Directly Affects Lubrication

Pressure must be given careful consideration in the solution of any lubricating problem and the selection of the right lubricant for press bearings or gears. It is evident that under

Effect of Manner of Drive

A recent survey of lubrication practice in British paper making mills, as compared with American practice, has developed some interesting and useful information, particularly to those who are concerned with manufacture and operation of calender stacks. Methods of drive have been given especially careful study, with a view to ascertaining relative advantages of driving through the second roll instead of the bottom roll, as is customary in American mills.



Courtesy of Beloit Iron Works.

Fig. 9—One of the latest types of super calender and winder installations showing open side arrangement. Practical lubrication of this type of machine has been materially simplified.

Advantages of the Second Roll Drive

From a lubrication point of view this has resulted in considerably improved bearing conditions; it is also claimed to have introduced other features of great importance to the paper maker, viz.:

The power required to drive the stack is reduced.

Heavy stacks equipped with plain babbitt bearings can be started up without the necessity of lifting the upper rolls.

The finish of the sheet is said to be considerably improved, due to greater slippage, particularly between the bottom and second rolls.

Slippage as developed with bottom roll drives is said to occur higher up the stack than when second roll drive is practiced. It is claimed that this latter gives greater slippage at the last roll passage in finishing the sheet. In other words, instead of starting the finish at the top of the stack in a more or less gradual manner, the glaze is imparted more instantaneously by the bottom rolls as the sheet leaves the stack. This is regarded as being conducive to a more uniform and greatly improved finish. Furthermore, if improved finish is not desired, second roll driving is claimed to give the same finish with much less pressure on the top roll.

Lubrication has been found to be materially facilitated in mills where the stack is driven through the second roll, for the bearings of the bottom roll have then only to carry the weight of the stack, with less resultant unit pressure. This means that drive stresses are carried by bearings that have to carry but little weight. It has also been found that pressure on the top roll bearing can be reduced, to somewhat overcome the usual difficulties which develop in the imposing of this pressure upon the cap of the bearing. But most important of all, it has been found that the necessity for special lubrication at starting, in the interest of reducing starting torque, can be eliminated.

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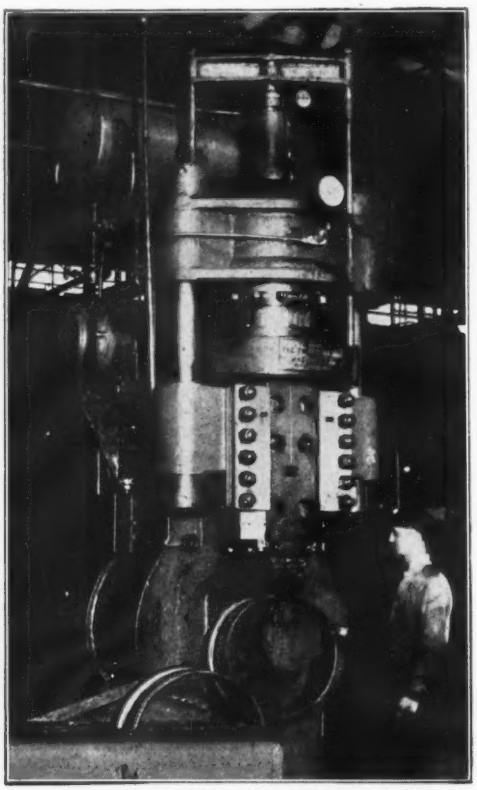
average conditions the greater the operating pressure between any two wearing elements, the heavier and more resistant must be the lubricating film, in order to prevent metal-to-metal contact, and squeezing-out of the lubri-



Courtesy of The French Oil Mill Machinery Co.

Fig. 1—Showing a hydraulic press used for the manufacture of automobile tire rims. This is a completely self-contained unit, with pumping equipment mounted on the press. The oil used in the hydraulic circuit also serves as a lubricant for certain of the moving parts.

cating film from between the wearing surfaces. Where bearings are involved, proper bearing grooving and adequate gear tooth and bearing area will aid materially in maintenance of the lubricating film.

With certain types of wearing elements the danger of impaired lubrication, due to direct pressure, can be partially prevented by enclosed construction and operating the parts in a bath or flood of lubricant. Relative to the development of such pressures, however, it must be remembered that the period of maximum intensity is relatively brief. In other cases, pressure can be met with pressure, the lubricant being maintained within the clearance spaces under the prevailing pressure of some form of pumping device, such as a mechanical force feed lubricator or pressure grease system.

Lubricant Characteristics

Regardless of the means of application, however, a certain degree of adhesiveness, and sufficient viscosity or consistency must be prevailing characteristics of the lubricant itself. To make any other than generalized statements as to the viscosity range of an oil for bearing service would be unwise. Too much will depend upon press construction, manner of operation, the type of service and design of the lubricating system. It will be far better to study all these in detail, in order that the severity of the duty may be realized. With such knowledge as a basis, and an understanding of what is actually involved when we speak of viscosity or consistency, etc., the problem of subsequently selecting either oils or greases to function effectively should be materially simplified.

As has already been stated, it is practicable to use either oil or grease for the lubrication of many of the wearing elements of metal forming machinery. The ultimate factor will involve the type of lubricating equipment provided, the operating conditions, such as speed and bearing pressures, and details of construction, such as manner of grooving. By virtue of the size, number of bearings, and bulky nature of such machines, it has been deemed advisable in many cases to provide some form of positive, automatic lubrication. Greater convenience should thereby result, with frequently marked savings in labor, and reduction of hazards to operators, due to the decrease in the amount of attention necessary. Gearing, on the other hand, will usually require manual application of gear lubricants, unless bath lubrication is provided for. This, of course, requires a suitable casing or enclosure to prevent lubricants from being thrown and wasted.

When speeds and loads are not excessive bath lubrication can be accomplished with a comparatively fluid gear lubricant. Under higher speed conditions, however, or where the lower part of the casing may not be sufficiently oil tight, a more inert lubricant may be advisable. A high degree of adhesiveness is essential under such conditions; this is a characteristic of those straight mineral lubricants of from 1000 to 2000 seconds Saybolt viscosity at 210 degrees Fahr., which have proven particularly adaptable to gear service of this nature. Normally, such lubricants will be applied by hand, but they are so enduring in service and so resistant to the squeezing-out effects of high tooth pressures, and the throwing-off effects of centrifugal force that frequency of re-lubrication can be materially decreased.

It is interesting to state, however, that some attention has been given to the development of mechanical means of applying heavier lubricants to press gears, it being claimed that such equipment will involve marked savings in labor and lubricant. On the other hand, a more

or less extensive and perhaps costly piping layout would have to be considered on most machines where any such lubricating system is to be applied.

THE TREND TOWARD CENTRALIZED LUBRICATION

Study of the trend in development of lubricating systems for heavy duty press machinery has indicated marked tendency toward centralized pressure lubrication, unit equipment being confined only to accessible parts where minimum hazard in adjustment may prevail. Both oils and greases have proved to be suited to the operating requirements, according to the means of application. As a result, today, lubrication by means of centralized pressure can involve either grease or oil according to the design of the lubricating system. The features of any such means of lubrication, under adequate pressure, include positive delivery of lubricant to insure maintenance of a sufficient film between the bearing surfaces, the exclusion of non-lubricating foreign matter, decided economy of lubricants, easy adjustment and a minimum of hazard in handling or filling.

Grease Systems

Controlled distribution of comparatively heavy bodied lubricants has been a most interesting problem in the study of automatic lubrication. There are a number of ways by which this can be accomplished and the lubricants impelled to the various points of delivery. In all, however, power in some form or other must be used.

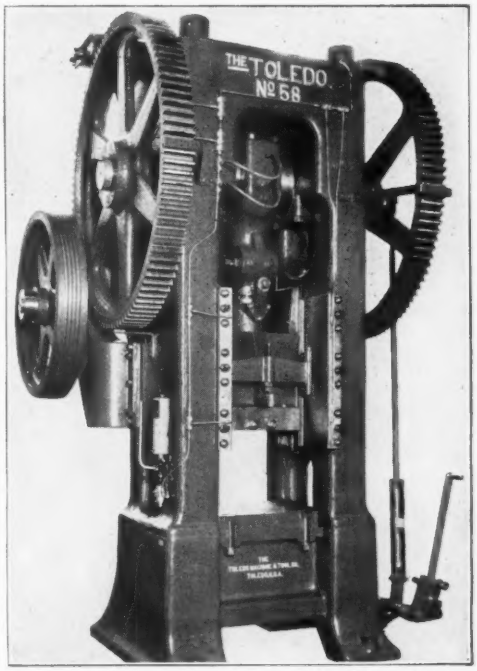
Where positive piston displacement types of metering valves are employed at each point to be lubricated, hydraulic power has been found to be especially adaptable, as a means of valve control. In such a system either one or two lubricant supply lines can be connected to each valve according to the nature of the service. For heavy duty machinery, dual lines can be used where desirable; one serving to load the respective valves periodically with the right amount of lubricant, the other functioning as the outlet or discharge.

Electric power or compressed air is also employed. Certain designs also eliminate the necessity for springs, check valves or restricted port openings. By virtue of the constant pressure which is exerted upon the lubricant, positive flow is insured by elimination of air pockets. It is important to remember that formation of air pockets will be affected by the body of the lubricant, heavier products being more conducive to retention of air within the lubricant itself.

Methods of Application

Certain types of centralized pressure greasing systems use the pressure gun to excellent advantage. In its usage it can either be designed as a directly connected unit, thereby becoming an integral part of the system, or a portable unit can be used. The portable gun is of decided value as a general piece of plant lubricating equipment, inasmuch as it can be used quite as effectively in connection with individual lubricators as with a centralized system. It can furthermore be used with the spring type of cup with equal dependability. This combination is decidedly advantageous for the lubrication of inaccessible or hazardously located bearings on many types of machinery.

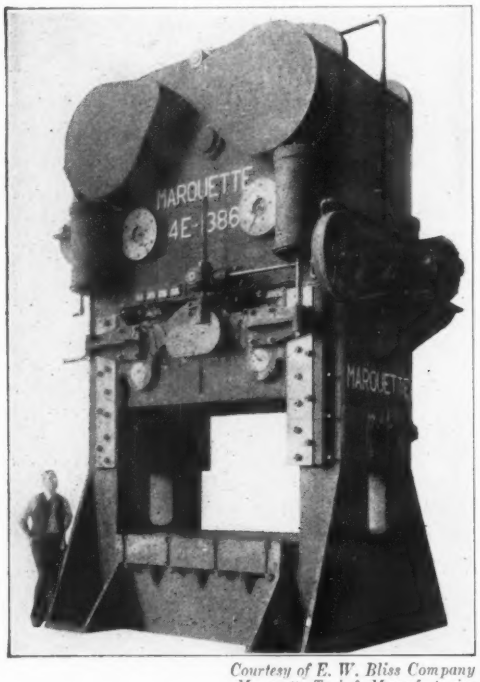
As a general rule, by using a grease cup carrying a spring of particular tension plus a suitable orifice, flow of grease therefrom can be very accurately controlled. Furthermore, it can be noted by observation of the indicator attachment. In many such devices, however, the greatest pressure and consequently the most positive flow will be developed just after the cup is filled. As the spring expands and the lubricator becomes discharged, however, there will be a tendency towards reduction of pressure. In the refilling of such a cup it is only



Courtesy of E. W. Bliss Company and The Toledo Machine and Tool Co.

Fig. 2—Showing a straight side single crank press equipped with the Trabon system of automatic high pressure force feed lubrication. This system is so arranged that the valves in the lubricating system are operated in sequence, with indicating means to show that the circuit has not been completed if any clogging occurs in the system at any point.

necessary to attach the pressure gun to the fitting located in the base, and work the discharge of the gun until the indicator shows the cup to be filled. There is no necessity for removal of the cover, as may be true with those



Courtesy of E. W. Bliss Company and Marquette Tool & Manufacturing Co.

Fig. 3—Showing a four-point drawing and stamping press with hydro-pneumatic drawing cushions. This press is equipped with the Farval duo-line lubricating system with motor drive, positive pump action and separate indicators at each bearing feed.

cups which are more strictly of the hand pressure type. In consequence there is more positive assurance that the grease charge will not become contaminated by dust or dirt in the course of handling.

Pressure guns can be operated by compressed air, electric power, or simply hand or foot power, according to the type of gun and the pressure desired. The former develop the higher pressures. Where a relatively simple hand pressure grease gun is used, the impression may be gained that this should be classified with the hand pressure or screw-down type of cup. Hand pressure as applied to a grease gun, and spring type cup, however, does not react directly on the bearing; it must be first converted to mechanical energy by doing work in compressing the spring in the grease cup. From this point on lubrication is automatically maintained by the mechanical action of the spring upon the adjacent plunger which bears upon the grease charge to force it to the point to be lubricated.

Power Drives Give Higher Pressures

In service where grease lubrication is essential under considerably higher pressures than can be obtained through the average spring type of cup, application of lubricant under controlled power is advantageous. It assures positive and complete cleaning of bearing grooves and clearance spaces prior to relubrication. This is especially important where conditions of operation may be conducive to entry and accumulation of dust, dirt and other non-lubricating foreign matter, as in the operation of so many metal presses.

The pressure gun always requires a certain amount of manual handling, irrespective of its method of operation. The gun itself must be moved about, flexible hose must be handled, fittings must be wiped clean before attachment of the hose or gun connection, and finally the gun must be put into operation. All this requires time, care and good judgment. The latter is especially essential in determining when a bearing has been completely relubricated. In bearings of the anti-friction type the amount of grease the bearing will hold can be approximately controlled by judicious installation of a suitable vent in the upper part of the bearing. Such a vent also serves to relieve any pressure within the bearing, to prevent the development of back pressure upon the lubricant, which might cause leakage around the housing in case the grease is not able to expand freely, especially under higher operating temperatures.

Where pressure gun fittings are concentrated at a central panel or point of control, the labor essential to lubrication will be reduced. This has been accomplished with such success that today it can safely be stated that centralized pressure grease lubrication is a practicable and comparatively economical procedure, distinctly advantageous in enabling reduction of hazard to the operating personnel.

Pressure Lubrication Assures Clean Bearings

Pressure is also beneficial in forcing out old grease and dirt from certain types of plain bearings. Care is necessary, however, in determining when this has been completely accomplished and when to shut off the pressure and cease forcing in new grease. Otherwise waste may result. If this method is properly carried out bearing life can be materially improved. On the other hand, if the operator is careless, unobservant, or continues to apply lubricant beyond the necessary extent, he will not only waste grease, but may also cause development of a sloppy condition around the machine. A slight bulge of fresh grease at a bearing end will usually indicate that complete re-lubrication has been accomplished, with minimum waste of the new product.

In any such system of grease lubrication, the possibility of constant pressure causing separation of certain types of grease which have been improperly manufactured must be fully realized. For this reason the use of pressure should be carefully studied with respect to the type of grease and the length of the distributing pipes, for loss of oil may result in marked decrease of lubricating value

Pressure Gun Designs

For unit lubrication of smaller types of presses, the hand pressure grease gun is often the most suitable device, due to its ability to operate by means of localized pressure. Grease guns of this type will usually be capable of developing several thousand pounds pressure per square inch. They are practicable either with or without hose connections, according to the location of the part to be lubricated and the type of fitting for which they are adapted.

Pressure can be applied either before or after attachment of the gun to the fitting. A frequent method of developing the necessary pressure is to force down a suitable plunger by means of a threaded stem which screws into a bushing in the head of the gun. Another type of gun involves pumping action by means of the handle and a suitable pressure retaining device.

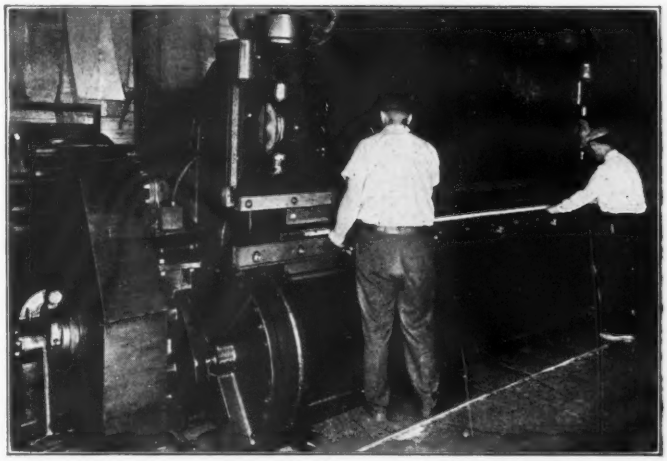
Where pressure is to be developed before attachment of the gun to the fitting, a suitable check valve must be installed in the tip. In certain guns the act of attachment opens this valve and automatically permits passage of lubricant to the bearing clearance. This sudden application of fresh grease under adequate pressure is of distinct advantage in clearing the bearing of used lubricant, and especially dirt if it has accumulated to cause partial clogging of oil grooves.

Grease guns which are designed to function with check valves eliminate the necessity of relieving the pressure before detaching the gun from the fitting and enable pressure to be raised before attachment, thereby reducing the possibility of twisting off the fitting. The use of direct or swivel joint connections also does away with the possibility of leaks in the flexible hose. These factors are especially important where bearings are to be cleared of grease which has been allowed to remain too long in the grooves or clearance spaces and consequently become gummed, caked or mixed with dirt or abrasive metallic materials.

The Mechanical or Power Lubricator

Devices of this nature are frequently of considerably greater grease capacity than the hand or foot pressure gun. In general, they are capable of holding 50 pounds of grease or more. The smaller capacity guns are chiefly of the hand service type; that is, after pressure is developed by power, the grease is discharged by the operation of a pump handle or lever. A ball or check valve at the base of the pump automatically closes at the end of each stroke to retain all pressure that may have been built up. For efficient operation this check valve must be inspected at frequent intervals to insure cleanliness. In such lubricators pressures of from 1000 pounds upward are readily developed in the handling of greases of medium consistency.

Where heavier or more inert grades of lubricants must be used, however, the electric or pneumatic compressor has been found to be adaptable. Such lubricators are usually of higher capacity than the hand service type, in certain cases holding as much as 400 pounds of lubricant. In this latter capacity a multilead discharge manifold is frequently installed to enable the lubrication of a number of points simultaneously. Such compressors can be either electrically driven, or designed to take their air from an adjacent compressed air line. In other respects, the principles of design of the power lubricator or compressor are much the same as those involved in the hand service type of device. To insure positive flow, especially at lower temperatures, the distribution piping should be about one-half inch in diameter, especially where long leads extend to remote parts of the press.

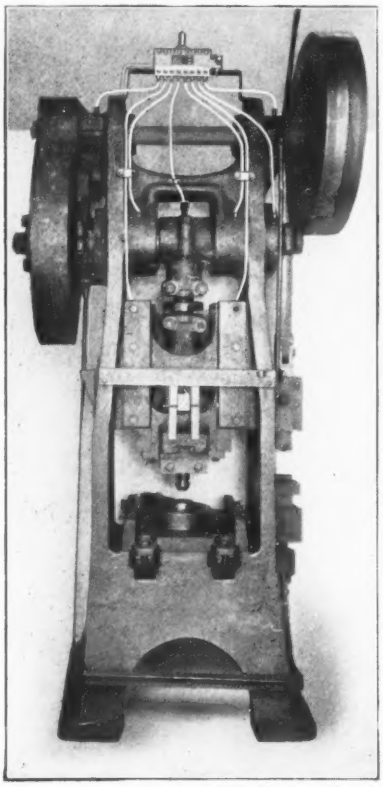


Courtesy of Farrel-Birmingham Company, Inc.

Fig. 4—Showing a Rafter all-steel Press-Brake. Automatic lubrication is provided on this unit by installing the gears in oil-tight housings. Bearings are grease lubricated by pressure gun, although provision can also be made for automatic force feed oiling.

OIL CIRCULATION

Oil lubrication is applicable where bearings or gear housings are so designed as to retain oil without appreciable leakage, and where adequate pressure can be maintained on the oil



Courtesy of Gits Brothers Manufacturing Co.

Fig. 5—Showing means whereby an air operated oiling system can be applied to a press, with provision for automatic circulation of oil to all bearings.

film in all bearing clearances to withstand the pressures developed by the shafts during operation. Circulation of comparatively fluid oils is especially advantageous in service where higher temperatures may prevail and where cooling is a partial function of the lubricant. Obviously, an excess of oil delivered to any press bearing which may be running warm, either due to load or the proximity of hot metals, can be kept from actually becoming over-heated if sufficient cool oil is constantly passed through the clearance to carry away a certain amount of heat.

Automatic operation of any such system is, of course, a decided advantage, although the extent to which it can be accomplished has been subject to considerable discussion. Certain authorities feel that the unit idea whereby each bearing is designed for individual control of lubrication will reduce the possibility of extended difficulties should faulty lubrication of any particular part develop.

Gravity circulation of oil has some advantage, due to its relative simplicity and the absence of costly automatic controls. Gravity circulation, on the other hand, is limited in regard to the amount of pressure available. Where this may be low, it may affect the viscosity of the oil which should be used.

The Advantage of Adequate Pressure

Oil circulation under constant pressure, of course, overcomes the objections pertinent to gravity circulation. A typical circulating system will involve a suitable oil reservoir, a pump for transmission of oil either to an overhead auxiliary tank, or directly to the bearing to be served, and the necessary distributing pipes to each of the latter. Each line should be fitted with a sight feed device and adequate means for individual adjustment of oil flow. Means will also be necessary for drainage or transmission of used oil back to the base reservoir or sump tank.

Such a system is advantageous in that it provides for sufficient settling of the oil to insure precipitation of the majority of any foreign matter that may have been picked up by the oil in passage through the bearings. Furthermore, since the latter are flood lubricated they will normally be washed free from accumulations of foreign matter, and cooled to a certain extent.

It is also perfectly practicable to provide for adequate pressure either by gravity or pumping, to maintain a sufficient pressure on the oil films to in part serve to resist such operating or reaction pressures as may be involved on certain of the bearings.

Relation of Fluidity to Effective Oil Flow

With increased oil pressure, the viscosity can often be somewhat reduced. This reduction in body of the lubricating film is compensated for by the added volume involved and the pressure under which the oil is applied.

Certain limits, however, control the viscosity or comparative fluidity of the oil, as well as the pressure. The pour test requires special consideration, for in cold weather or under low temperature starting conditions, the rate at which the oil will return to the settling tanks may be affected. Obviously, if the oil should become too sluggish at any time, flow off from a gear housing or bearing might be impaired to develop backing up of the oil in the system. Should any bearings be improperly sealed, this oil might find its way to the exterior of the case and lead to waste and a sloppy condition on the operating floor.

Any decrease in fluidity, due to an originally too high viscosity or pour test may also develop

marked increase in power consumption. This would prevail throughout the system, for not only would the circulating or oil delivery pumps be called upon to do extra work, but also the press drives themselves might feel the extra duty demanded due to the increase in internal friction within the lubricant itself.

Increase in the automatic nature of any such system calls for more careful consideration of these factors of pour test and relative fluidity, for the normally extensive piping layouts and the possibility of development of abnormal friction losses within the system itself may cause reduction in oil flow to a sufficient degree to require severe overloading of the pumps in order to maintain the desired flow to the bearings, and keep the oil supply in the tanks at the proper level.

THE MECHANICAL FORCE FEED LUBRICATOR

It is also advantageous to lubricate certain types of press bearings with a measured quantity of oil delivered under sufficient pressure to counter-act in part the operating pressures which prevail. The essential feature is a sufficient degree of oil-tight construction to obviate appreciable loss of oil through leakage, and reduction in oil pressure. The mechanical force feed lubricator has been found to be especially adapted to such service where oil lubrication is desirable.

Devices of this nature are operated under varying pressure by the machines to which they are attached. They can be built with a number of oil feeds, each being controlled by its individual pump in the oil reservoir. The mechanical force feed lubricator is a decidedly convenient and positive device. It can be equipped with separate visible feed lines to the respective bearings, to enable control and maintenance of an uninterrupted supply of oil at all times, provided that periodic refilling is attended to. It is practicable, furthermore, to equip such a lubricator with a return line, used oil being carried back to the reservoir for recirculation. In this way economy is increased.

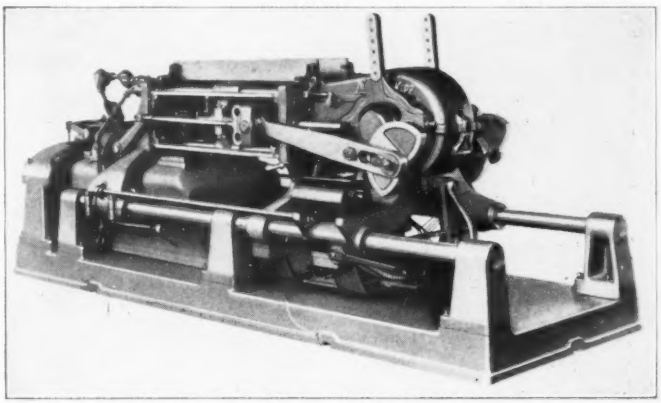
Mechanical force feed lubricators, being practically always driven by the machinery which they serve, only function when the latter is in operation and at a proportional speed. The pumping capacity and rate of oil feed is therefore variable. By suitable adjustment of the lubricator it can be very accurately regulated to meet whatever lubricating requirements may be involved.

The advantage claimed for the mechanical force feed lubricator as a one-time oiling device is that a positive pre-determined supply of clean fresh oil can be furnished to the bearings in as nearly as possible the correct amount to meet the requirements of effective lubrication. Waste can, thereby, be reduced to a minimum and general conditions of cleanliness improved. As a rule, there will be very little drip from bearings so lubricated, provided they have been correctly designed.

Drip Lubrication

The sight feed oil cup and wick oiler are also claimed to give the requisite degree of lubrication on some types of press bearings. The former, of course, will involve individual lubrication of the respective bearings as a rule, with consequent need of individual attention as to filling and adjustment. Sight feed oilers, however, are advantageous in that they normally permit of observation of the oil content from the operating floor.

The wick feed oiler, in turn, can be of either the individual or manifold type. Each is economical from a labor-saving point of view, though they may perhaps involve oil waste if improperly designed, adjusted or controlled. The manifold type can be built on very much the same lines as the wick oiler employed on certain classes of marine steam engines. Wick oiling is suitable provided that the wicking is of proper texture and in good condition, for the wick will serve as an effective strainer to insure delivery of clean oil to the bearings. Periodic cleaning of wicks, of course, is advisable if the above is to be continuously maintained.



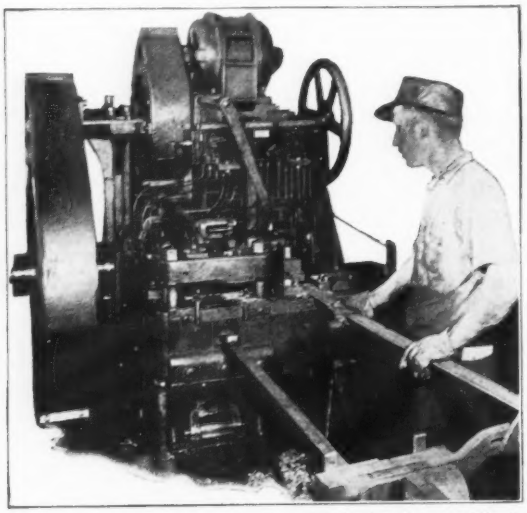
Courtesy of Madison-Kipp Corporation

Fig. 6—View of automatic die casting machine equipped with a Madison-Kipp Model FD Lubricator, which automatically lubricates all important bearings under controlled pressure.

There are, however, many bearings on certain types of presses, etc., which will not require such positive means of lubrication. Usually they can be hand-oiled two or three times a

day. To facilitate this the spring-cover type of oil cup can be installed.

Normally the same grade of oil as used in a mechanical force feed lubricator or circulating oiling system will adequately take care of such



Courtesy of McCord Radiator & Mfg. Co.

Fig. 7—Showing another type of press equipped with a McCord force feed oiler. Lubricator leads to the important bearings can be clearly followed.

other wearing elements as may require drip or hand oiling. Such a product should be a highly refined, straight mineral oil having a viscosity range of from 200 to 400 seconds Saybolt at 100 degrees Fahr.

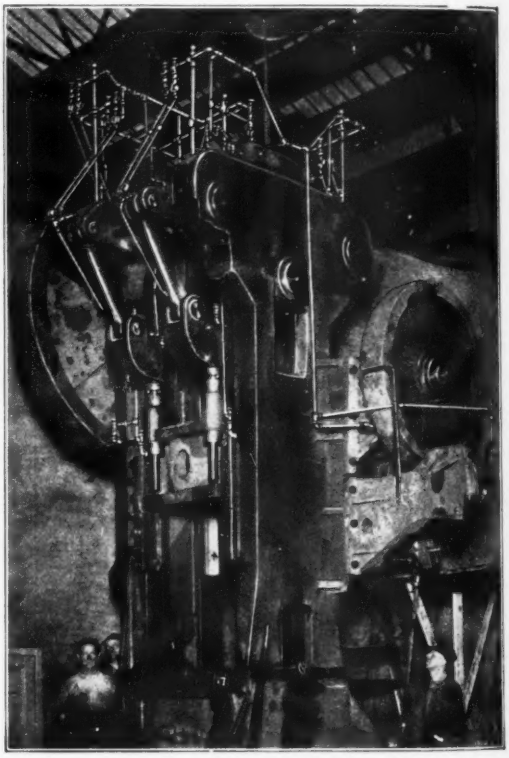
SLIDES AND GUIDES

In the power press or metal stamping machine, slides or guides carry the reciprocating elements. This insures perfect and constant alignment in order that such cutting, stamping, perforating or forming as may be involved can be carried out with the desired accuracy. It is possible to adjust these slides on most machines, and in this way, wear can be compensated for, unless, of course, it has been allowed to occur to an extreme. Proper maintenance of adjustment, along with adequate lubrication, should assure marked reduction in solid friction.

Pressure, speed, and the method of application of the lubricant are the essential factors which must be considered in the lubrication of sliding surfaces. The lubrication of practically any sliding surface wherein the action of gravity must be counteracted by the adhesiveness and body of the lubricating film will oftentimes be a comparatively difficult matter due to the wiping action of the reciprocating elements and the possibility of contamination of the intermittently exposed lubricating film with dust, dirt or metallic particles. Absolute protection against these latter is practically impossible. The only solution of the problem and the best insurance against the development of abnormal wear is to select the lubricant most carefully from a viscosity or film strength viewpoint and to apply it with adequate generosity to insure the flowing off of heavier contaminating foreign matter by gravity.

Lubricating oils of medium to heavy viscosity will normally meet this requirement on the average machine. Due to the necessity for a certain amount of flood lubrication, especially where contamination may be excessive, greases as a rule will be too resistant to the action of gravity to function satisfactorily, even though their usage might reduce the total consumption of lubricant.

In deciding upon how heavy such an oil should be, one must consider pressure and temperature, as well as the prevailing clearance. It is difficult to state definitely just what the viscosity should be in measured terms, i.e.,



Courtesy of Wm. W. Nugent Company

Fig. 8—Side view of a drawing press equipped with the Nugent oiling and filtering system. Oiling starts and stops automatically with the press and the use of telescopic and knuckle joints effectively prevents leakage.

seconds Saybolt at 100 degrees Fahr., or 210 degrees Fahr., for so many installations will be distinctive in their operating condition. As a rule, however, 300 to 750 seconds Saybolt at 100 degrees Fahr., should indicate the high and

low limits. Such an oil should be comparatively adhesive, especially where wiping or thrust pressures may be high for resistance to thinning out of the lubricating film is very essential, otherwise boundary lubrication and the possibility of actual metallic contact may result.

Thin Oil Film Lubrication

The effect of friction upon power consumption in the operation of machinery can be materially reduced by improvement of the degree of smoothness of the metallic surfaces of the moving parts. Friction is, of course absolutely essential to the comfort and convenience of our everyday life. It is, however, a detriment to the economical operation of machinery, for it gives rise to wear and is the primary reason for lubrication, in the interest of preventing abnormal temperature rise. The purpose of this series of articles is to discuss the benefits to be derived from improvement of surface finish; the theory involved in the study of frictional resistance; the abrasive effect of absolutely clean metallic surfaces; the value of oiliness as an adjunct to lubrication; and the methods developed for counteracting extreme pressures between metallic surfaces in close contact.

Surface Finish

Perfect finish of any metallic surface is an ideal which is impossible to achieve. The most beautifully finished surface plate is covered with "high spots," and the best that can be done is to increase the total number of high spots, and to reduce the difference in level between these plateaus and the intervening valleys. By extremely nice workmanship it is possible to prepare a flat surface, say a 2-inch diameter block of hard steel, true to about 1/10 the wave length of sodium light. Reduced to a more usual system of measurement, this means that the difference in level between the top of a plateau and the bottom of a valley is about two-millionths of an inch.

This is a minute distance, according to our usual conception of size, but it is over twenty times the length of an average molecule of oil. The nearest approach to an absolutely true plane surface is the central portion of the surface of a very large pool of clean mercury standing in a dish on a vibrationless table. Other very true surfaces may be produced by cleaving certain crystals, such as calcite.

What is a Polished Surface?

In practical service solid friction can be most effectively counteracted by lubrication where the moving parts are as smooth and true as possible in geometrical figure. As perfect smoothness is approached by finishing, surface irregularities are reduced. An absolutely smooth surface would be invisible. This is most closely approximated by a perfectly still surface of clean mercury. Here the only departure from perfect smoothness would be due to the surface agitation of the molecules, an effect of temperature; but this agitation, of course, would be far too minute for the eye to perceive.

In an attempt to approach a natural smooth surface by artificial means, metallic surfaces essential to machine operation are ground and polished. The gross irregularities of the surfaces are reduced by grinding, finer and finer abrasives being used as the operation proceeds.

Under the microscope it can be seen that even the most finely ground surface is covered with scratches; the better the grinding, the finer the scratches. Beilby* has shown that polishing and grinding are distinct processes. In the polishing process, the extreme outer skin of the surface is caused to flow. Minute projections above the average surface are worn down, and minute furrows are filled up or bridged over. It is rather startling to realize how mobile the surface molecules of a solid have been proved to be, as evidenced by the flow phenomena during polishing, but it must not be forgotten that even with the use of jeweller's rouge on a soft pad, high values of unit pressure may be reached.

In modern practice, the final polishing process is more conveniently and economically done with the bearings and journals in place. They are allowed to rub against each other, with a lubricant between them, the effect of this "running in" process being to bed them thoroughly together, and to produce on the surfaces a very high polish.

Fluid and Boundary Friction

Although it is not the purpose of this article to deal with fluid friction, it is perhaps necessary at this stage to point out the essential difference between the two types. In fluid or viscous friction the sliding metal surfaces are separated by a relatively thick layer of oil. The typical case is that of an ordinary journal bearing. The diameters of journal and bearing differ by a definite amount, and when running, the oil fills completely the annular space between the metal surfaces. The frictional loss is low, and is dependent on the viscosity of the oil.

* Beilby: "Aggregation and Flow of Solids," (1921)

In boundary lubrication, on the other hand, the oil film between the sliding surfaces is exceedingly thin. The influence of surface irregularities is of importance here because of the close approach of the main boundaries. Indeed, when high spots come together the intensity of pressure may be such that all bulk oil is squeezed out, leaving a film which may be only a few molecules thick.

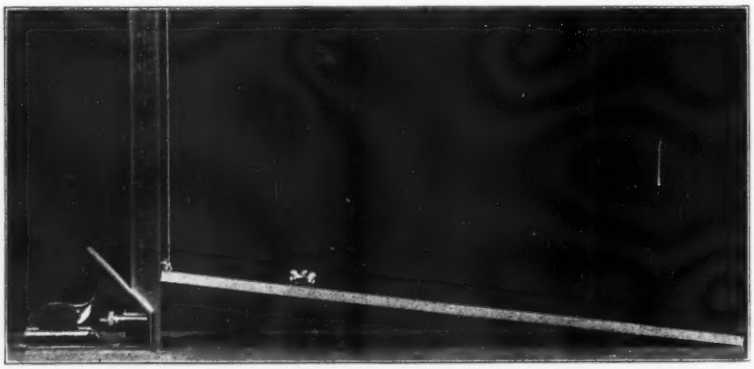


Fig. 1—Showing arrangement of a tilting track and slider as designed for studying the laws of friction. The angle of the slider can be very accurately varied at will.

Meshed gears, particularly certain types such as the hypoid, are lubricated under boundary film conditions. Here frictional losses are very much higher than in fluid lubrication, normal wear is much greater, and the danger of seizure is very real. In boundary film lubrication, the effect of viscosity of the oil on frictional loss is unimportant. On the other hand, that elusive property known as "oiliness" requires very careful consideration, as will be discussed in a subsequent article.

Coefficient of Friction

It is a matter of common observation that when a solid object is laid on a horizontal, flat surface and the latter is gradually tilted, the slider will begin to slip down the slope when the angle of tilt is sufficiently great. The nature of the slider and track, and particularly the state of their sliding surfaces, has a profound influence on the slipping angle. A piece of wet soap on a smooth wet surface will slip at a very small angle of tilt, as experiments in the bathtub will show. A flat steel slider placed in a pool of oil on a steel track will also slip at a very small angle of tilt. These two examples illustrate extremely well lubricated surfaces, where the friction is of the fluid or viscous type. Suppose, now, the steel slider is cleaned by means of carbon tetrachloride and placed upon a similarly cleaned steel track. The angle of tilt before slide occurs will be much greater, probably in the neighborhood of 8 or 10 degrees.

A tilting track and slider such as is shown in Figure 1 forms a very useful device for studying the phenomenon and laws of friction under thin film conditions. This apparatus has been much neglected in favor of more elaborate and costly equipment, but in the hands of a skilled experimenter, and when careful attention is given to the physical condition of the surfaces, quite valuable information may be obtained by its use.

The track is very simply constructed, being merely a flat bar of metal, say hard steel, with the working surface very nicely polished. It is arranged to tilt from its horizontal position on a level table, about one end, and means are provided for measuring the angle of tilt. This can easily be done by measuring the height of the tilted end of the bar above the table. This height, divided by the length of the bar, gives, of course, the sine of the angle of tilt. The tangent can be read from tables and, as is well known, the numerical value of the tangent of the angle at which slip occurs is the coefficient of static friction. The coefficient is defined as a number obtained by dividing the frictional drag between the two surfaces by the load pressing them together. For any two given solid surfaces in contact, the coefficient has a maximum value at the instant they start to slip; this is called the coefficient of "static" friction.

The form of the slider is important, if we are interested in learning what is the influence of the area of contact between the two opposed metal surfaces, under specified conditions of lubrication.

Amonton's law of Sliding Friction states that friction is proportional to the weight of the slider, and is independent of the area of contact. If we desire to satisfy ourselves of the truth of this law, it is obvious that the first difficulty encountered is the determination of the true area of contact.

A so-called "flat" surface for the slider is unsuitable since the true area of contact is unknown. Only the high spots of even the best flat surfaces are in contact under ordinary loads. A spherical slider, on the other hand, laid on a plane track, is believed to give an area of contact which can be more accurately computed from the elastic properties of the slider and track materials. It can be shown that the radius of the contact circle is proportional to the cube root of the product of the weight of the slider and its radius of curvature.

It is rather surprising to learn what high intensities of pressure are reached when a hard steel ball merely rests on a hard steel flat. The case of a standard ½ inch diameter ball was calculated. The area of the circular contact spot is slightly over one-millionth of a square inch, and the maximum intensity of pressure in the center of the spot is 25,300 lbs. per sq. in. It is by virtue of this enormous intensity of pressure that the spherical slider is so well adapted for the study of boundary film lubrication phenomena. Even if the track carries a relatively thick layer of oil, the ball sinks rapidly through the gross oil layer and very soon reaches the limiting and stable position, where the two metal surfaces are separated only by an exceedingly thin film of the lubricant. It is probable, as indicated by Hardy's work† that a perfect sphere and plane would be separated only by a double mono-molecular layer of oil.

With these thoughts in mind, it is easy to understand why, with the tilting track and spherical slider, the same coefficient of static friction is obtained whether the track is flooded with oil or merely carries an invisible film. If, for instance, we start with clean metal and then rub the surface with a piece of filter paper moistened with the test oil, slip will occur at the same angle of tilt as if there were visible oil present. Indeed, Hardy found that exposure of the clean metal of the track to air saturated with oil vapor was quite sufficient to give efficient boundary film lubrication. He concluded that the critical value of friction, that is to say, the value which is independent of the quantity of the lubricant present, is that of surfaces so lubricated as to be in equilibrium with saturated vapor. The critical value is also the lowest value which can be obtained in boundary friction.

The surface molecules of a solid, since they, unlike the interior molecules, are not completely surrounded by other molecules, are capable of exerting attractive forces on the oil molecules which are placed on the surface. It is Hardy's view that boundary friction is due to the effect of this molecular attraction on the properties of the oil. When two solid faces are separated by a thin layer of lubricant, the oil molecules are believed to become aligned by the attractive force of the solid surfaces into a more or less definite arrangement, depending on the shape of the molecules. Although the oil in bulk form is fluid, the absorbed film has no real fluidity, because the attractive forces of the solid surface have destroyed the random arrangement of molecules which is characteristic of fluidity, and have conferred on the absorbed layer a more stable configuration approaching that existing in a solid body.

Consider two absolutely flat and smooth solid faces, of the same material—say steel—placed face to face with a very small amount of oil between them. The oil molecules actually in contact with each face are strongly held by the attractive forces existing at the steel surfaces. The molecules of a typical oily substance, such as oleic acid for instance, would be oriented at the surface, with the carboxyl group attached to the metal and the hydrocarbon group directed away. Successive layers of these molecules would be aligned less and less completely, since the strength of the attractive forces of the surface decreases rapidly with distance from the surface. Langmuir‡ finds that the effect of the surface forces on the molecules in a given layer is about half of that in the next lower layer.

Suppose, now, an attempt is made to slide one steel surface over the other. There is resistance to motion, and it is necessary to increase the tangential force to a certain definite value before slip will occur. This slip occurs approximately midway between the two steel surfaces because here the orienting effect of the surface forces is at a minimum. The character of the slip depends on the thickness of the oil film. If the film is only two molecules thick, the outer ends of the molecules slip relative to each other. As the film thickness increases, the molecular orientation becomes less pronounced, and the slip approaches that between the random molecular layers of the oil in bulk. The minimum force required to produce slip is a measure of the maximum tangential stress which the molecular structure involved is capable of bearing.

It must be remembered that the film we are dealing with here is only a few molecules thick. It is such a film as would exist between the spherical surface of the steel ball and the flat steel track, shown in Figure 1. In all such cases we are operating in the boundary film region, and the fact that it is necessary to apply a minimum tangential force before slip occurs is evidence that in these thin oil films the field of attraction which has its seat in the molecular boundary of the metal surfaces must extend at least as far out, though greatly diminished in intensity, as half the thickness of the layer of lubricant. In fluid or viscous lubrication, on the other hand, the slip plane is far outside the influence of the molecular attraction zone, and the smallest applied force will cause one surface to move relatively to the other.

(To Be Continued)

†Hardy & Doubleday—Proc. Roy. Soc. 100-A (1922) p. 555.

‡ Langmuir—Evaporation, Condensation and Absorption, Journ. Am. Chem. Soc., July, 1932—p. 2813.

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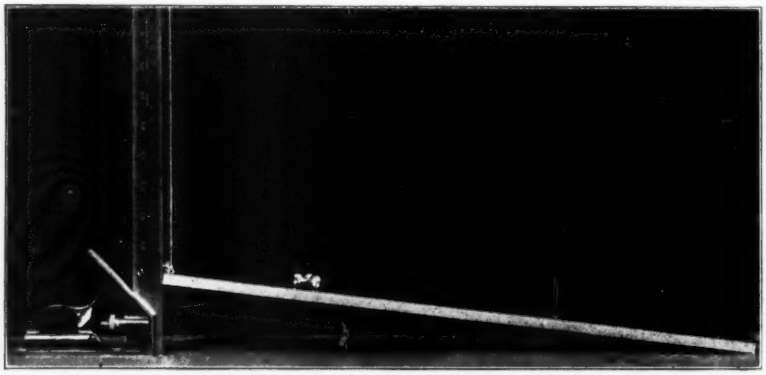

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Lubrication Service

The careful attention which has been given to the application of the theory of oil film maintenance to heavy duty machinery has devised a very definite function for the lubricating engineer as an exponent of lubrication service.

This service begins with the purchase of virtually any type of lubricant. Frequently it can be of the utmost value to plant executives who may be unfamiliar with opera ing conditions and the duty which will be required of their lubricant . It can be rendered most effectively where the lubricating engineer is taken into intimate consultation and full advantage taken of his knowledge of handling and application of lubricants, and the properties necessary for the work to be done. It is normally possible to call in such a specialist from any reputable manufacturer of lubricants, although large plants will frequently also retain their own talent for the purpose of improving the co-operation with the manufacturer, and extending their studies relative to lubrication economies.

The plant lubricating engineer is a decided asset wherever a considerable volume of machinery is involved, and where impaired lubrication in any unit might seriously disrupt a production schedule. The duties of a plant lubricating engineer should cover direct supervision of storage facilities and means of application of all lubricants; the preparation of oiling schedules and decision as to periods for cleaning and flushing of lubricating systems; the instruction of operators as to the advantages to be derived from careful lubrication of their machinery; co-operation with the chief engineer and master mechanic in the installation of new equipment or maintenance of existing units; and study of operating conditions to determine their bearing upon selection of lubricants of specific properties or chemical characteristics. In this respect the plant lubricating engineer can check up on the specifications of any lubricant which may be offered to the purchasing department, or he can prepare his own, based on test data which he has developed, according to prevailing operating conditions.

Lubricating engineering service as developed by certain of the most progressive manufacturers of lubricants is of decided advantage to those plants whose volume of production does not warrant the employment of a plant lubricating engineer. It is absolutely essential, however, that the sincerity of this service be investigated and that it be sponsored by a reputable oil company. To seek advice from anyone who does not have due regard for the title "Lubricating Engineer" might work to the disadvantage of the buyer, in that there would be no assurance that lubrication recommendations as offered would be dependable. Too often the unscrupulous marketer will make such recommendations to meet price competition rather than machine requirements.

On the other hand, lubricating engineering service of repute is one of the greatest assets available to the operator of mechanical equipment. It affords an especially economical way for industrial or power plant executives to avail themselves of expert technical advice in regard to the solution of problems of lubrication, and the selection of lubricants capable of maintaining plant production most effectively, and in keeping with the accepted theories of oil film development. The lubricating engineer who represents a reputable manufacturer of lubricants will, as a rule, be intimately conversant with the many variables that should be considered—in general, far more so than any engineer employed in a similar capacity by any specific industrial concern. This is quite natural, for the latter will have had far less opportunity to study and familiarize himself with lubrication as applied to mechanisms required in plants other than in his own field of operations.

Such operations, however, are met with daily by the oil company specialist. He can approach the steel mill executive and quote experience with high temperature lubrication problems in the cement plant quite as readily as he can discuss the matter of low carbon content with the Diesel operator, and draw a contrast as to its added advantages in air compressor service. In other words, he is so broadly trained by practical experience that his advice should never be overlooked. It is especially advantageous where cost-per-gallon of lubricating oils is unduly stressed, for he can prove conclusively that the latter is normally far outweighed by the potential savings in power consumption and maintenance costs.

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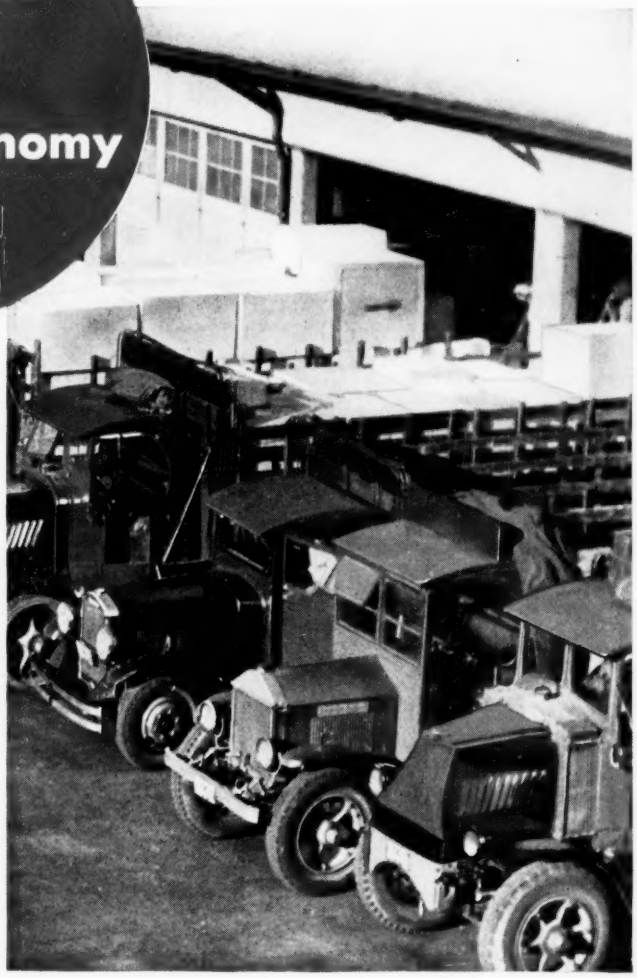

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